COMPARATIVE ANALYSIS OF GEODETIC TECHNIQUES FOR MONITORING DEFORMATION IN LARGE STRUCTURES

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1.1 BRIEF BACKGROUND TO THE STUDY

- Deformation Survey is the systematic measurement and tracking of the alteration in the shape or dimensions of an object as a result of stress induced by applied loads.

- Deformation monitoring is to guarantee the structure (building) safety and detect the abnormal changes, make judgment on the stability and safety of the building.

- The selection of the method of measurements depends upon the accuracy requirements for the survey.

- The implication of using deformation monitoring method that is not suitable in term of accuracy for the monitoring of a particular engineering structure has a significant effect on the magnitudes and directions of the determined deformations

1.2 STATEMENT OF THE PROBLEM

- None comparison of the accuracy of two or more deformation monitoring methods for deformation monitoring of engineering structures.

- Determination of the structural integrity of Palm House, Benin City which has been in existence for over 40 years without monitoring. The building was commissioned in 1974, it is an old building.

- The tenth floor got burnt sometime years ago and was totally abandoned for about ten years without usage.

1.3 AIM AND OBJECTIVES

Aim

The aim of this study is to comparatively analyse geodetic techniques for monitoring deformation in large structure, with a view to determining which of the two horizontal methods is better in terms of accuracy. Its objectives are:

Objectives

- To carry out observations (Total Station, Level and GPS observations) at 6 different epochs at interval of three months and processing of the observations to determine the coordinates and heights of the monitoring networks points.

- To carry out least squares adjustment and statistical analysis on the observations to determine the reliability as well as the precision, accuracy and uncertainty of the adjusted observations and those of the adjusted parameters.

- To determine the magnitudes and confidence ellipses/intervals at 95% confidence level of the horizontal and vertical displacements of the monitoring points

- To compare the determined displacement magnitudes with their corresponding confidence ellipses/intervals to determine if the displacements are significant or not.

- To determine and differentiate the movement of the 10th floor from that of the entire building by comparing the results obtained from the two horizontal (GPS and total station) methods.

- To compare the results obtained from the two horizontal (GPS and total station) methods so as to determine which of the two horizontal methods is better in terms of accuracy.

1.4 JUSTIFICATION OF THE STUDY

Comparing the displacement magnitudes of the monitoring points with their respective 95% confidence level, and the accuracy of the two horizontal methods will enable:

- The structural integrity of the building to be determined.
- The movement of the tenth floor to be differentiated from that of the entire building.
- The determination of which of the two methods is better in terms of accuracy so as to assist users (Geodesists and Engineers) in the selection of the method to apply in terms of the purpose of measurements, the magnitude and directions of the expected deformations.

1.5 STUDY AREA

- Palm House is one of the Edo State Secretariat buildings in Benin City (Figure1).
- It is a high rise building located along Benin Sapele road in Oredo Local Government Area of Edo State.
- The building is an eleven story building. It is 45m in length, 15m in breadth and 35m in height.
- It was commissioned 10th February, 1973.
- The study area lies between latitudes 06° 01' 54"N and 06° 25' 35"N and longitudes 05° 26' 23"E and 05° 50' 05"E.

Figure 2 shows the map of the study area.

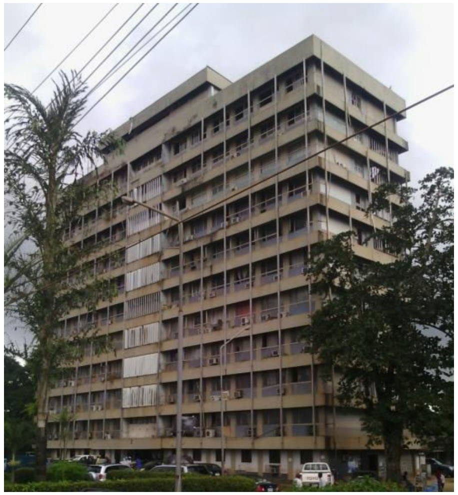


Fig. 1: Palm House, Benin City

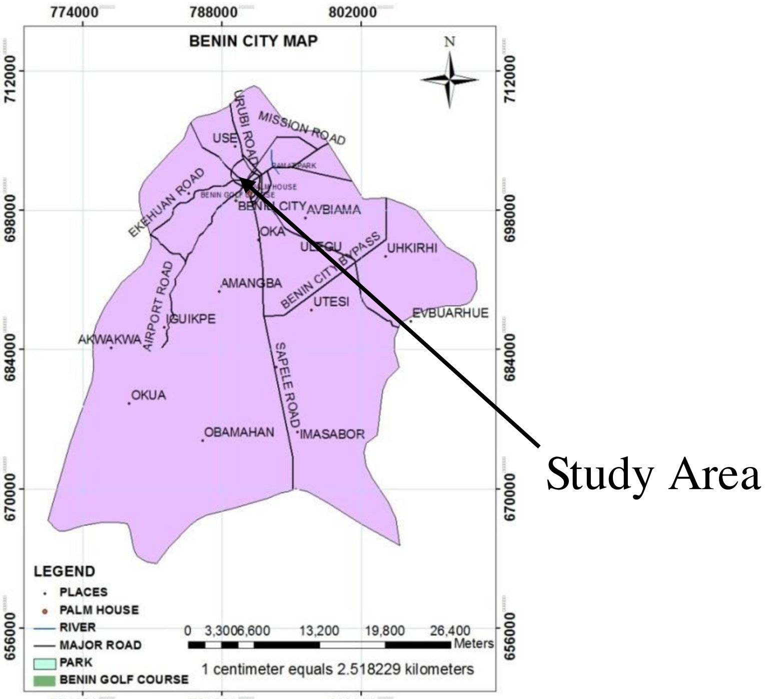


Fig. 2: Map of Benin City Showing Study Area

Source: Ministry of Lands and Surveys, Benin City.

1.6 SCOPE OF THE STUDY

The scope of the study is as follows:

- Marking out of monitoring points (studs) on the building.
- Establishment of reference points (stations) on stable grounds or platforms round the building using DGPS.
- Determination of the orthometric heights of the reference stations using differential levelling.
- Carrying out levelling, total station and GPS observations in different epochs on the building.
- Processing of the GPS observations and the transformation of the processed coordinates to Minna Datum coordinates using the seven datum transformation parameters.
- Least squares adjustment and statistical analysis of the processed and transformed GPS coordinates, the levelling data (orthometric heights) and the Total Station observations.

- Evaluation of displacements magnitudes between the first epoch and the subsequent epochs observations, in horizontal and vertical relationship.

- Evaluation of the horizontal and vertical displacements confidence ellipses/intervals at 95% confidence level.

- Evaluation of significance of the computed displacements magnitudes between the first epoch and the subsequent epochs observations by comparing the computed displacements magnitudes with their corresponding confidence ellipses/intervals to determine if the reported movements were actual movements of the structure or not.

- Determination and differentiation of the movement of the 10th floor from that of the entire building by comparing the results obtained from the two horizontal (GPS and total station) methods.

- comparison of the results obtained from the two horizontal (GPS and total station) methods in order to determine which of the two horizontal methods is better in terms of accuracy.

2.0 THEORETICAL FRAMEWORK

2.1 DEFORMATION SURVEY / MONITORING

- Terrasurv (2015) described deformation survey as a survey to determine if a structure or object is changing shape or moving.
- Traditional deformation monitoring techniques can be divided into geotechnical measurements and geomatics based surveys (Detchev, 2011).
- The geotechnical measurements are made with extensometers, tiltmeters, micrometers, etc., which yield the magnitude of the deformation relative to reference marks on the actual object being monitored.
- Geomatics-based surveys involves the use of precision Levels, Theodolites and Electronic Distance Measurement (EDM) devices, Global Navigation Satellite System (GNSS) Positioning, 3D Laser Scanner, Photogrammetry and InSAR. Geodetic methods supply information on the absolute and relative displacements (changes in coordinates) of the monitored object.

2.2 PURPOSE OF DEFORMATION MONITORING

- The main purpose for monitoring and analysis of structural deformations is to determine whether or not movement is taking place and subsequently whether the structure is stable.

2.3 LEAST SQUARES ADJUSTMENT MODEL

The system of observation equations is presented by matrix notation as (Mishima and Endo 2002):

$$V = AX - L \qquad (1)$$

where,

A = Design Matrix, X = Vector of Unknowns, L = Calculated Values (*lo*) Minus Observed Values (l_b), V = Residual Matrix

That is,

$$\begin{array}{ccccccc} V & & A & & X & & L \\ \begin{pmatrix} v_1 \\ v_2 \\ \dots \\ v_m \end{pmatrix} & = & \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{pmatrix} & & \begin{pmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{pmatrix} & - & \begin{pmatrix} l_1 \\ l_2 \\ \dots \\ l_m \end{pmatrix} \end{array} \qquad (2)$$

Estimated parameter

$$X = (N)^{-1}(t) \qquad (3)$$

Where, $N = \left(A^TWA\right) =$ Normal Matrix,

$t = \left(A^TWL\right)$, $N^{-1} = \left(A^TWA\right)^{-1} = Q_{XX}$,

$X = \left(A^TWA\right)^{-1}\left(A^TWL\right)$ = Estimate,

W = Weighted Matrix

A Posteriori Variance, $\hat{\sigma}_o^2 = \dfrac{V^TWV}{m-n} = \dfrac{V^TWV}{r}$ (4)

A Posteriori Standard Error, $\hat{\sigma}_o = \sqrt{\dfrac{V^TWV}{m-n}} = \sqrt{\dfrac{V^TWV}{r}}$ (5)

Where, $m - n = r$ = Degree of freedom

The model for the computation of the standard error of the adjusted parameters is given as: (Ameh, 2013):

$$\hat{\sigma}_{xi} = \hat{\sigma}_\circ \sqrt{Q_{nn}} = \sqrt{\hat{\sigma}_o^2 Q_{nn}} \qquad (6)$$

Where,

Q_{nn} is a diagonal element of the inverse of the normal matrix

Error Ellipse

Semi-major Axis, $\sigma_{x^{\mathrm{I}}}^{2} = \frac{\sigma_x^2 + \sigma_y^2}{2} + \left[\frac{(\sigma_x^2 - \sigma_y^2)^2}{4}\right] + \sigma_{xy}^2,$

(7),

Semi-minor Axis, $\sigma_{y^{\mathrm{I}}}^{2} = \frac{\sigma_x^2 + \sigma_y^2}{2} - \left[\frac{(\sigma_x^2 - \sigma_y^2)^2}{4}\right] + \sigma_{xy}^2$

Orientation = $\tan 2\theta = \frac{2\sigma_{xy}}{\sigma_x^2 - \sigma_y^2}$ (8)

Trace

The model for the computation of trace of the variance-covariance matrix is given as (Caspary, 1988):

$$\mathrm{tr}\ A = \sum a_{ii} \qquad (9)$$

Redundancy Number

$$r_i = q_i p_i, \qquad (10)$$

$$r_{Av} = \frac{n - R(A)}{n} \qquad (11)$$

r_i = Redundancy number, p_i = Weight of the ith observation.

q_i = Diagonal element of the estimated residual cofactor matrix, Q_v,

r_{Av} = Average redundancy number

$n - R(A)$ = Degree of freedom or redundant observation,

$R(A)$ = Number of unknown parameter,

n = Number of observation.

Standardized Residual

$$\text{Standardized Residual } (T_i) = \frac{\text{Adjusted Observation Residual } (v_i)}{\text{Residual Standard Deviation } (\sigma_{v_i})}$$

Standardized Residual Rejection Constant, Tau Statistics

$$\tau_{v,\alpha} = \frac{t_{v-1,\alpha} . \sqrt{v}}{\sqrt{(v-1) + t^2_{v-1,\alpha}}} \qquad (12)$$

Where,

$\tau_{v,\alpha}$ = Critical value from the Tau distribution at redundancy v and significance level α

v = Number of degree of freedom

α = Significance level

$t_{v,\alpha}$ Critical value from the student's distribution at redundancy v and significance level α

Distance Observation Equation

$$\frac{dS_{ij}}{dX_i} = -\left(\frac{X_j^o - X_i^o}{S_{ij}^o}\right) \quad \frac{dS_{ij}}{dX_j} = \left(\frac{X_j^o - X_i^o}{S_{ij}^o}\right)$$

$$\frac{dS_{ij}}{dY_i} = -\left(\frac{Y_j^o - Y_i^o}{S_{ij}^o}\right) \quad \frac{dS_{ij}}{dY_j} = \left(\frac{Y_j^o - Y_i^o}{S_{ij}^o}\right) \qquad (13)$$

Azimuth Observation Equation

$$\frac{dA_{ij}}{dX_i} = \left(\frac{Y_j^o - Y_i^o}{S_{ij}^{o\,2}}\right) \quad \frac{dA_{ij}}{dY_i} = -\left(\frac{X_j^o - X_i^o}{S_{ij}^{o\,2}}\right)$$

$$\frac{dA_{ij}}{dX_j} = -\left(\frac{Y_j^o - Y_i^o}{S_{ij}^{o\,2}}\right) \quad \frac{dA_{ij}}{dY_J} = \left(\frac{X_j^o - X_i^o}{S_{ij}^{o\,2}}\right) \qquad (14)$$

Where,

(X's and Y's) = Unknown parameters, S_{ij}^0 = distance computed from approximate coordinates, $X_i^o, Y_i^o, X_j^o, X_j^o$

Computation of Magnitude and Direction of Displacement

$$\begin{cases} x_j^{k+1} - x_i^k = dx \\ y_j^{k+1} - y_i^k = dy \\ z_j^{k+1} - z_i^k = dz \end{cases} \qquad (15)$$

$x_j^{k+1}, y_j^{k+1}, z_j^{k+1}$ = Coordinates of last epoch

x_i^k, y_i^k, z_i^k = Coordinates of preceding epoch

Horizontal movement $ds = \sqrt{(dx)^2 + (dy)^2}$ (16)

Vertical movement $dH = \sqrt{\left(z_j^{k+1} - z_i^k\right)^2} = \sqrt{(dz)^2}$ (17)

Direction of movement $(\alpha) = \tan \alpha_i = \frac{dy_i}{dx_i}$ (18)

2.4 DEFORMATION ANALYSIS

- The ultimate goal of the geometrical analysis is to determine if the reported movements are statistically significant.

The computed displacements = $|D_j| = \sqrt{(\Delta x_j)^2 + (\Delta y_j)^2}$ (19)

The corresponding 95% interval/ellipse = $E_j = 1.96\sqrt{(m_{\Delta j}^{k+1})^2 + (m_{\Delta j}^{k})^2} = 1.96\sqrt{M}$ (20)

where,

$$M = (m_{\Delta j}^{k+1})^2 + (m_{\Delta j}^{k})^2$$

$M = (m_{\Delta j}^{k+1})$ - Standard error in position for the K+1 epoch and

$= (m_{\Delta j}^{k})$ - standard error in position for the previous epoch k.

Then, if $|D_j| < E_j$, It implies that movement did not take place b/w epochs observations

But if on the other hand $|D_j| > E_j$ then we conclude that point movement has occurred

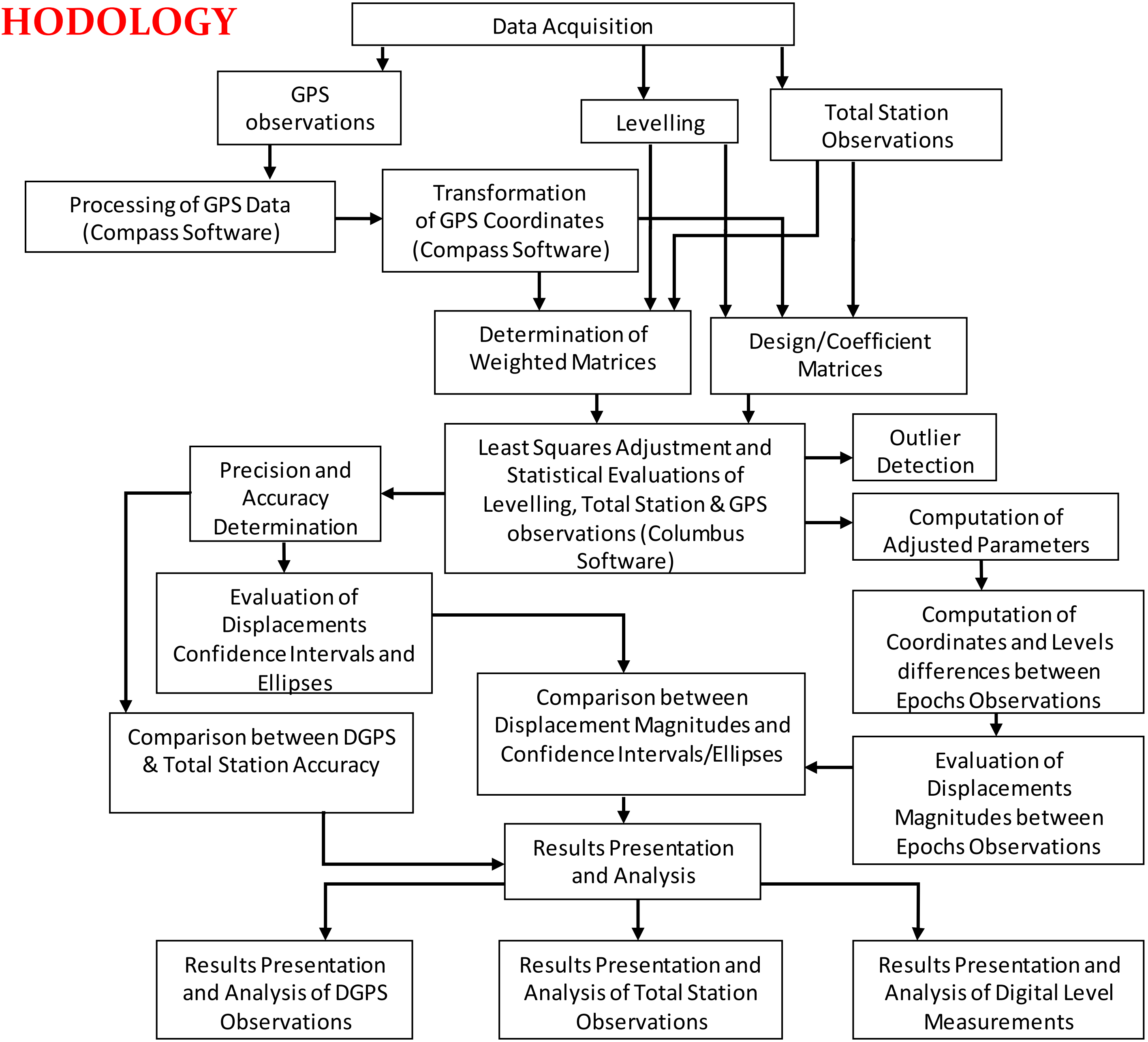
3.0 LITERATURE REVIEW

- About 40 previous studies were reviewed.

3.1 IDENTIFIED GAPS

- None of the reviewed studies on deformation monitoring of engineering structures compared any two horizontal methods in terms of their accuracy so as to determine the method that is better in terms of accuracy.
- None of the reviewed studies on deformation monitoring of high rise buildings segmented or partitioned the monitored object (building) into different sections
- Also, in the research works by Kok (2005), Ramin and Helmi (2009), and that by Vintilă et al (2014) the standard errors of the monitoring points were not analyzed statistically to see if the movements were significant or were as a results of measurement errors.

4.1 METHODOLOGY



Data Acquisition

GPS observations

Levelling

Total Station Observations

Processing of GPS Data (Compass Software)

Transformation of GPS Coordinates (Compass Software)

Determination of Weighted Matrices

Design/Coefficient Matrices

Least Squares Adjustment and Statistical Evaluations of Levelling, Total Station & GPS observations (Columbus Software)

Outlier Detection

Computation of Adjusted Parameters

Precision and Accuracy Determination

Evaluation of Displacements Confidence Intervals and Ellipses

Computation of Coordinates and Levels differences between Epochs Observations

Comparison between Displacement Magnitudes and Confidence Intervals/Ellipses

Evaluation of Displacements Magnitudes between Epochs Observations

Comparison between DGPS & Total Station Accuracy

Results Presentation and Analysis

Results Presentation and Analysis of DGPS Observations

Results Presentation and Analysis of Total Station Observations

Results Presentation and Analysis of Digital Level Measurements

Fig. 3: Flow Chart of the Proposed Methodology

4.2 DATA ACQUISITION PROCESS

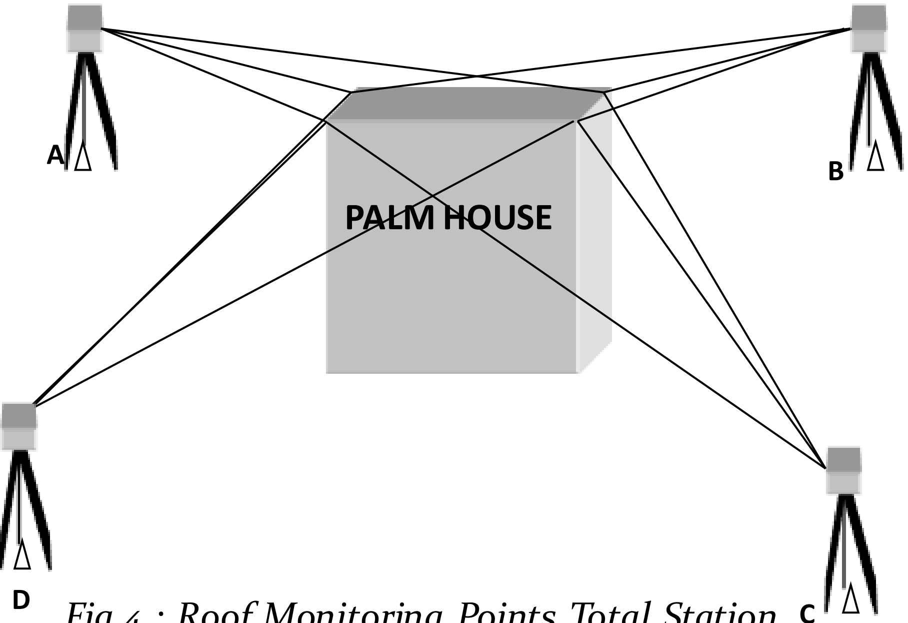


Fig.4 : Roof Monitoring Points Total Station Observation Network

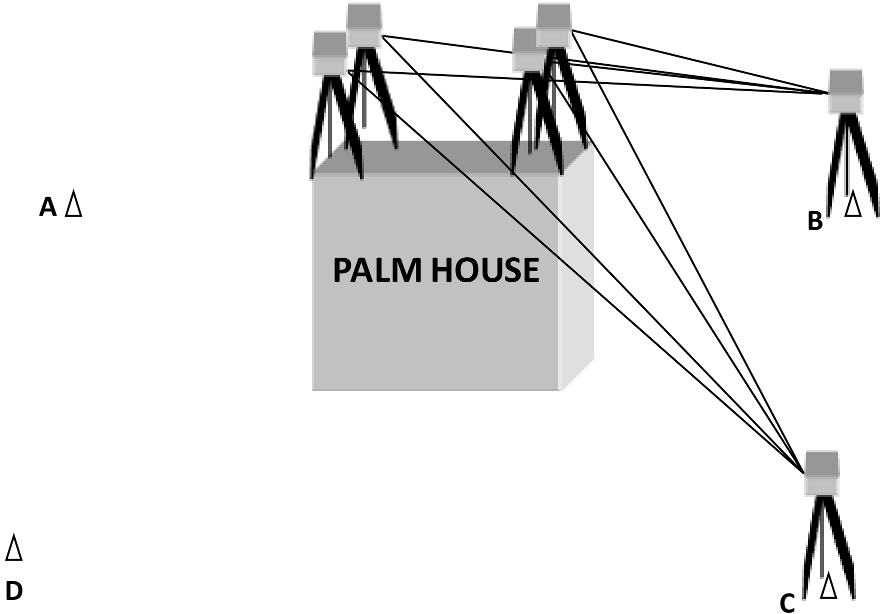


Fig. 5: GPS Observation Network

Fig. 6: Base receiver at Control Station FGPEDY06

Fig. 7: Base receiver at Reference Station C

Fig. 8: Rover receiver at Monitoring point M

Fig. 9: Total Station at Reference Station C

4.3 STATISTICAL EVALUATION

The statistical evaluations of the observations were carried out using Columbus software and were divided into computation of:

- A posteriori variance, a posteriori standard error, and standard errors of the adjusted coordinates and heights.
- Chi-square test on a posteriori variance factor.
- Redundancy number.
- Standardized residual.
- Residual rejection constant (tau statistics).
- Confidence region (error ellipses) of the adjusted positions.
- Height confidence intervals.

5.1 DATA ANALYSIS, PRESENTATION AND DISCUSSION OF RESULTS

5.1.1 Analysis of the Levelling, GPS and the Total Station Observations Data

- The closing error for the first loop was 0.0057m while that of the second loop was 0.0005m (Table 1) which were within millimetres standard. The orthometric height of each of the monitoring points was able to be reproduced from not less than three reference stations.

Table 1: Known and Observed Heights of the Closing Stations

Station	Description	$H_{(known)}$ (m)	$H_{(observed)}$ (m)	ΔH (m)
BC/BM03	Starting and Closing Station	54.026	54.0203	0.0057
C	Starting and Closing Station	52.1643	52.1638	0.0005

- The processing results of the six epochs DGPS observations were seen to have passed the Network Adjustment Test which implies that the normal matrix generated was a regular one and inverted accordingly for calculation of residuals.

- The total station observations results were seen to be in good shape and were accepted as the coordinates of each monitoring point were able to be reproduced from not less than three reference stations.

5.2 ANALYSIS OF THE ADJUSTED LEVELLING RESULTS USING LEAST SQUARES TECHNIQUE

Table 2: A Posteriori Variance and A Posteriori Standard Errors of the Six Epochs Levelling

EPOCH	A POSTERIORI VARIANCE (m)	A POSTERIORI STANDARD ERROR (m)
FIRST	0.0000037164	0.001927807
SECOND	0.0000038406	0.001959743
THIRD	0.0000037923	0.001947370
FOURTH	0.0000036267	0.001904380
FIFTH	0.0000035372	0.001880736
SIXTH	0.0000036312	0.001905559

- The maximum standard errors of the first to the sixth epoch adjusted heights were respectively 0.0120462, 0.0111885m, 0.0121685m, 0.0118998m, 0.0117522m, and 0.0119072m

- The minimum and the average redundancy numbers were respectively 0.4287 and 0.625.

- Computed standardized residuals less than residuals rejection constant.

- The maximum confidence intervals of the first to the sixth epochs adjusted heights were respectively 0.023603m, 0.0226232m, 0.0238426m, 0.023316m, 0.023027m and 0.023331m.

5.3 ANALYSIS OF THE ADJUSTED TENTH FLOOR MONITORING POINTS TOTAL STATION OBSERVATIONS RESULTS USING LEAST SQUARES TECHNIQUE

Table 3: A Posteriori Variance and A Posteriori Standard Errors of the Six Epochs Total Station Observations

EPOCH	A POSTERIORI VARIANCE (m)	A POSTERIORI STANDARD ERROR (m)
FIRST	0.17488	0.41819
SECOND	0.21221	0.46066
THIRD	0.20672	0.45467
FOURTH	0.18981	0.43568
FIFTH	0.16591	0.40733
SIXTH	0.22807	0.47757

- The maximum standard errors in northing and easting of the first to the sixth epoch adjusted coordinates were respectively 0.00064m and 0.00069m, 0.00068m and 0.00057m, 0.00067m and 0.00056m, 0.00065m and 0.00054m, 0.00060m and 0.00051m, and 0.00071 and 0.00059.

- The minimum redundancy number of the adjusted distances and azimuths were respectively 0.9999 and 0.0001 while the average redundancy number was 0.625.

- Computed standardized residuals less than residuals rejection constant.

- The maximum scaled semi-major axis and semi-minor axis of the six epochs adjusted coordinates were respectively 0.0019242m and 0.001689m.

- The traces of the first to the sixth epoch observations were respectively 0.0000035148m, 0.000002485m, 0.00000242m, 0.000002222m, 0.000001942m and 0.00000267m

5.3.1 ANALYSIS OF THE ADJUSTED ROOF MONITORING POINTS TOTAL STATION OBSERVATIONS RESULTS USING LEAST SQUARES TECHNIQUE

Table 3: A Posteriori Variance and A Posteriori Standard Errors of the Six Epochs Total Station Observations

EPOCH	A POSTERIORI VARIANCE (m)	A POSTERIORI STANDARD ERROR (m)
FIRST	0.23161	0.48126
SECOND	0.13834	0.37195
THIRD	0.17570	0.41917
FOURTH	0.10443	0.32316
FIFTH	0.18068	0.42506
SIXTH	0.17951	0.472369

- The maximum standard errors in northing and easting of the first to the sixth epoch adjusted coordinates were respectively 0.00092m and 0.00089m, 0.00065m and 0.00079m, 0.00099m and 0.00099m, and 0.00062m and 0.00074m.

- The minimum redundancy number of the adjusted distances and azimuths were respectively 0.9999 and 0.0023 while the average redundancy number was 0.667.

- Computed standardized residuals less than residuals rejection constant.

- The maximum scaled semi-major axis and semi-minor axis of the six epochs adjusted coordinates were respectively 0.0024234 m and 0.0024234 m.

- The traces of the first to the sixth epoch observations were respectively 0.000005577m, 0.000000755m, 0.000000958m, 0.000000569m, 0.000000985m and 0.000001027m

5.4 ANALYSIS OF THE ADJUSTED DGPS OBSERVATIONS RESULTS USING LEAST SQUARES TECHNIQUE

Table 4: A Posteriori Variance and A Posteriori Standard Errors of the Six Epochs DGPS Observations

EPOCH	A POSTERIORI VARIANCE (m)	A POSTERIORI STANDARD ERROR (m)
FIRST	0.0000044705	0.002114344
SECOND	0.0000003131	0.000559521
THIRD	0.0000002144	0.000463080
FOURTH	0.0000060425	0.002458150
FIFTH	0.0000043369	0.002082528
SIXTH	0.0000228554	0.004780734

- The maximum standard errors in northing and easting of the first to the sixth epoch adjusted coordinates were respectively 0.00045m and 0.00068m, 0.00027m and 0.00025m, 0.00019m and 0.00019m, 0.00032m and 0.00026m, 0.00029m and 0.00024m, and 0.00045m and 0.00029m.

- The minimum redundancy number of the adjusted change in northing, change in easting and the average redundancy numbers was 0.75

- Computed standardized residuals less than residuals rejection constant.

- The maximum scaled semi-major axis and semi-minor axis of the six epochs adjusted coordinates were respectively 0.001102m and 0.001665m

- The traces of the first to the sixth epoch observations were respectively 0.0000019786m, 0.000000392m, 0.000000223m, 0.000000425m, 0.000000308m and 0.0000051m

5.5 COMPARISON BETWEEN THE VERTICAL DISPLACEMENTS MAGNITUDES AND THEIR CORRESPONDING 95% CONFIDENCE INTERVALS

Table 5: Comparison of the Vertical Displacements Magnitudes with their Corresponding Confidence Intervals

MONITORING POINT		E	F	G	H	I	J
B/W 1ST & 2nd EPOCHS	MAG6NITUDE SQRT((ΔHT)^2) (m)	0.0003973	0.0000999	0.0001727	0.0008375	0.0028527	0.0002430
	1.96*(SQRT(M)) (m)	0.0252411	0.0307612	0.0251137	0.0241149	0.0313804	0.0256615
	DIFFERENCE (m)	0.0248438	0.0306613	0.0249410	0.0232774	0.0285277	0.0254185
B/W 1ST & 3rd EPOCHS	MAGNITUDE SQRT((ΔHT)^2) (m)	0.0006723	0.0008573	0.0008740	0.0010974	0.0009902	0.0013523
	1.96*(SQRT(M)) (m)	0.0252265	0.0320851	0.0257389	0.0230336	0.0308978	0.0239853
	DIFFERENCE (m)	0.0245542	0.0312278	0.0248649	0.0219362	0.0299076	0.0226330
B/W 1ST & 4th EPOCHS	MAGNITUDE SQRT((ΔHT)^2) (m)	0.0001253	0.0000143	0.0000678	0.0000071	0.0000459	0.0002682
	1.96*(SQRT(M)) (m)	0.0243898	0.0303226	0.0247557	0.0253692	0.0331881	0.0254743
	DIFFERENCE (m)	0.0242645	0.0303083	0.0246879	0.0253621	0.0331422	0.0252061
B/W 1ST & 5th EPOCHS	MAGNITUDE SQRT((ΔHT)^2) (m)	0.0000045	0.0001142	0.0001765	0.0001421	0.0000081	0.0001340
	1.96*(SQRT(M)) (m)	0.0242408	0.0301373	0.0246045	0.0252142	0.0329854	0.0249046
	DIFFERENCE (m)	0.0242363	0.0300231	0.0244280	0.0250721	0.0329773	0.0247706
B/W 1ST & 6th EPOCHS	MAGNITUDE SQRT((ΔHT)^2) (m)	0.0001092	0.0001999	0.0001907	0.0002366	0.0002984	0.0000477
	1.96*(SQRT(M)) (m)	0.0243972	0.0303317	0.0247632	0.0248320	0.0330608	0.0250652
	DIFFERENCE (m)	0.0242880	0.0301318	0.0245725	0.0245954	0.0327624	0.0250175

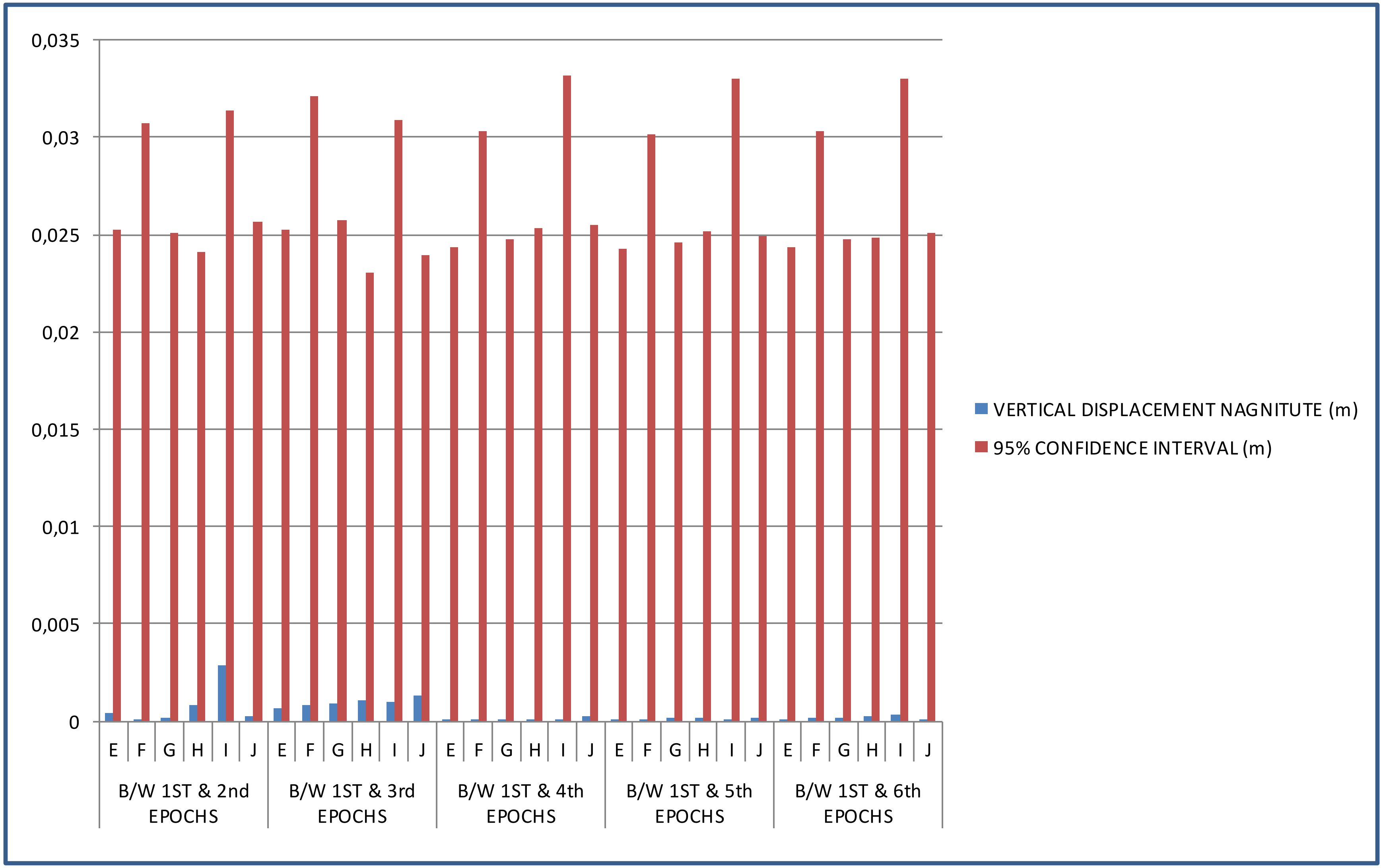


Fig 10: Plot of the Vertical Displacements Magnitudes and their Corresponding Confidence Intervals

5.6 COMPARISON BETWEEN THE TENTH FLOOR MONITORING PONITS TOTAL STATION OBSERVATIONS DISPLACEMENTS MAGNITUDES AND THEIR CORRESPONDING 95% CONFIDENCE ELLIPSES/REGIONS

Table 6: Comparison of the Horizontal (Tenth Floor Monitoring Points Total Station Observations) Displacement Magnitudes with their Corresponding Confidence Ellipses

MONITORING POINT		P	Q	R	S	T	U
B/W 1ST & 2nd EPOCHS	MAGNITUDE SQRT $((\Delta N)^2+(\Delta E)^2)$ (m)	0.000282	0.000400	0.000400	0.000376	0.000714	0.000339
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.001783	0.001977	0.001993	0.002009	0.002085	0.001900
	DIFFERENCE (m)	0.001501	0.001577	0.001593	0.001633	0.001371	0.001561
B/W 1ST & 3rd EPOCHS	MAGNITUDE SQRT $((\Delta N)^2+(\Delta E)^2)$ (m)	0.000449	0.000777	0.000400	0.000389	0.000446	0.000362
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.001775	0.001955	0.001977	0.002009	0.002063	0.001885
	DIFFERENCE (m)	0.001326	0.001178	0.001577	0.001620	0.001617	0.001523
B/W 1ST & 4th EPOCHS	MAGNITUDE SQRT $((\Delta N)^2+(\Delta E)^2)$ (m)	0.000449	0.000769	0.000581	0.000352	0.000714	0.000000
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.001760	0.001910	0.001963	0.001980	0.002011	0.001871
	DIFFERENCE (m)	0.001311	0.001141	0.001382	0.001628	0.001297	0.001871
B/W 1ST & 5th EPOCHS	MAGNITUDE SQRT $((\Delta N)^2+(\Delta E)^2)$ (m)	0.000114	0.000777	0.000581	0.000530	0.000707	0.000383
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.001724	0.001819	0.001926	0.001952	0.001949	0.001837
	DIFFERENCE (m)	0.001610	0.001042	0.001345	0.001422	0.001242	0.001454
B/W 1ST & 6th EPOCHS	MAGNITUDE SQRT $((\Delta N)^2+(\Delta E)^2)$ (m)	0.000273	0.000354	0.000400	0.000304	0.000412	0.000469
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.001798	0.002027	0.002008	0.002032	0.002128	0.001915
	DIFFERENCE (m)	0.001525	0.001673	0.001608	0.001728	0.001716	0.001446

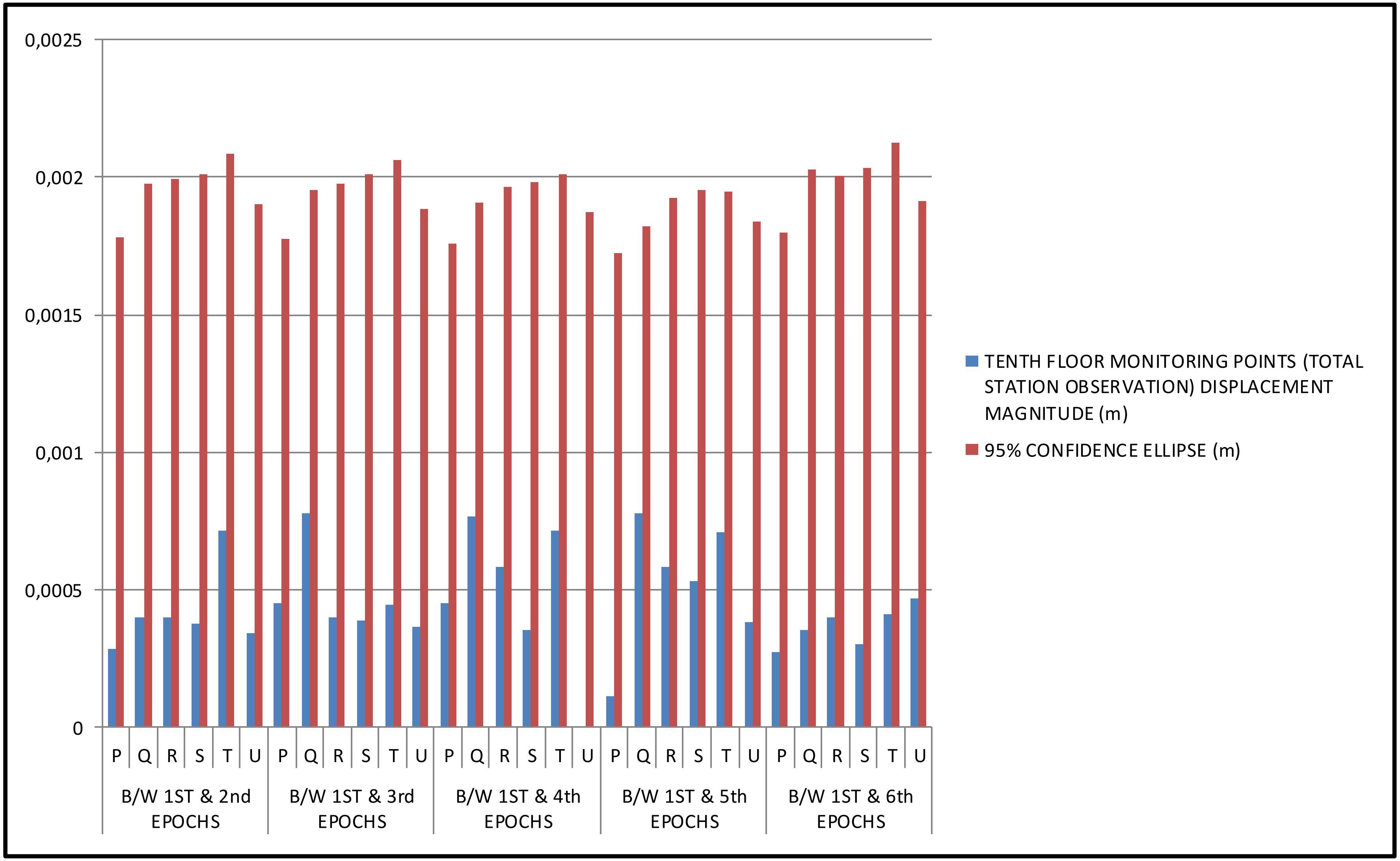


Fig 11: Plot of the Horizontal (Tenth floor Monitoring Points Total Station Observations) Displacements Magnitudes and their Corresponding Confidence Ellipses

5.6.1 COMPARISON BETWEEN THE ROOF MONITORING PONITS TOTAL STATION OBSERVATIONS DISPLACEMENTS MAGNITUDES AND THEIR CORRESPONDING 95% CONFIDENCE ELLIPSES/REGIONS

Table 6: Comparison of the Horizontal (Roof Monitoring Points Total Station Observations) Displacement Magnitudes with their Corresponding Confidence Ellipses

MONITORING POINT		K	L	M	N
B/W 1ST & 2nd EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.001273106	0.000518652	0.000859884	0.000700357
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.00262984	0.00219931	0.00288906	0.00206359
	DIFFERENCE (m)	0.001356734	0.001680658	0.002029176	0.001363233
B/W 1ST & 3rd EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.001273106	0.000669403	0.001150695	0.000735459
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.00266084	0.002247	0.00292553	0.00210461
	DIFFERENCE (m)	0.001387734	0.001577597	0.001774835	0.001369151
B/W 1ST & 4th EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.001729855	0.000994636	0.001968146	0.000697209
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.00259794	0.00215083	0.00285232	0.00202108
	DIFFERENCE (m)	0.000868085	0.001156194	0.000884174	0.001323871
B/W 1ST & 5th EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.000850941	0.000228035	0.000653682	0.000130384
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.00266084	0.00250251	0.00293523	0.00210998
	DIFFERENCE (m)	0.001809899	0.002274475	0.002281548	0.001979596
B/W 1ST & 6th EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.001399464	0.00063561	0.00084	0.000904434
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2+(m_{\Delta j}^{k})^2}$ (m)	0.00266084	0.00249644	0.00293005	0.00210998
	DIFFERENCE (m)	0.001261376	0.00186083	0.00209005	0.001205546

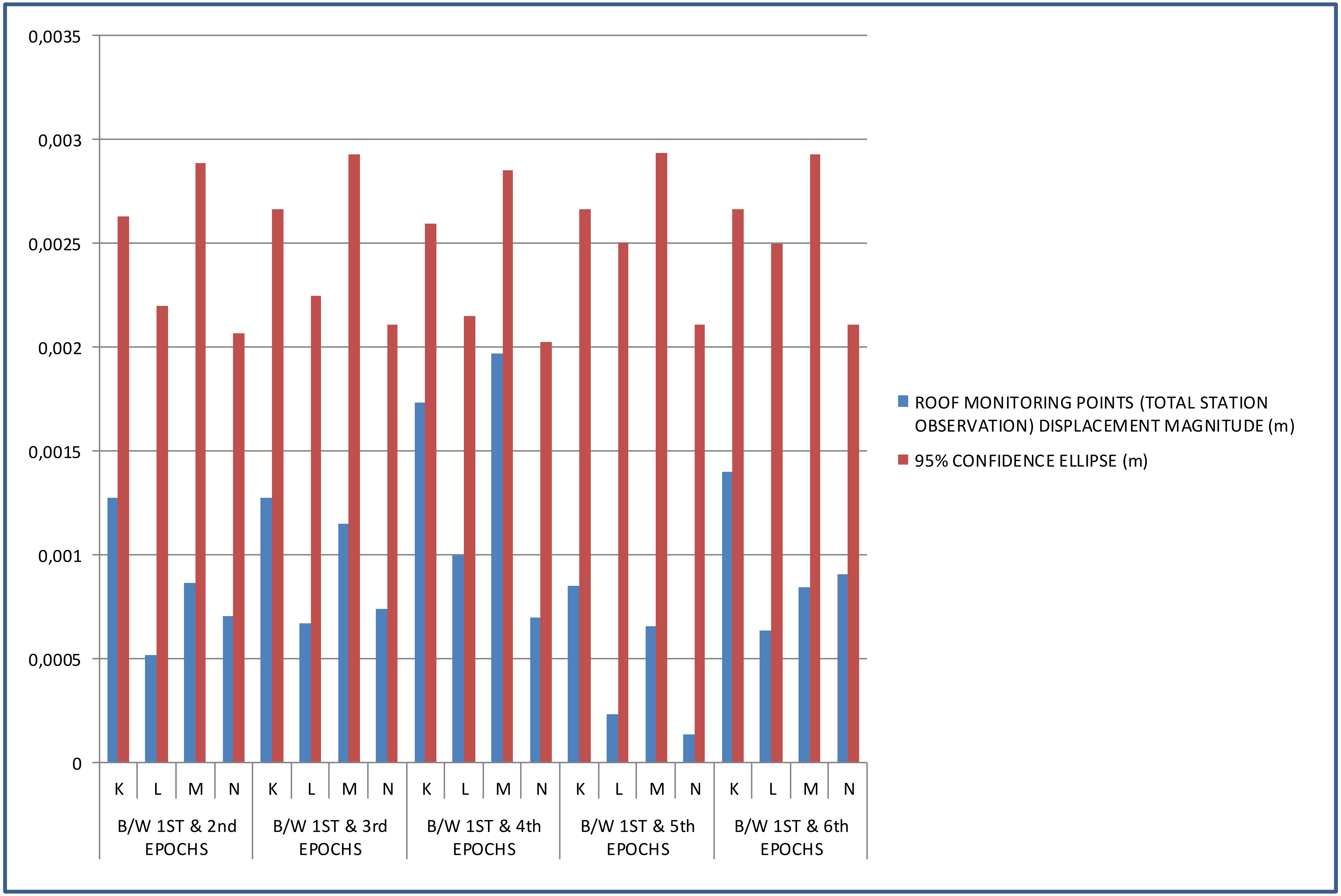


Fig 12: Plot of the Horizontal (Roof Monitoring Points Total Station Observations) Displacement Magnitudes and their Corresponding Confidence Ellipses

5.7 COMPARISON BETWEEN THE DGPS OBSERVATIONS DISPLACEMENTS MAGNITUDES AND THEIR CORRESPONDING 95% CONFIDENCE ELLIPSES

Table 7: Comparison of the Horizontal (DGPS Observations) Displacements Magnitudes with their Corresponding Confidence Ellipses

MONITORING POINT		K	L	M	N
B/W 1ST & 2nd EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.000121655	0.000628013	0.000471699	0.000642884
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2 + (m_{\Delta j}^{k})^2}$ (m)	0.00152855	0.00159086	0.00145582	0.0014549
	DIFFERENCE (m)	0.001406895	0.000962847	0.000984121	0.000812016
B/W 1ST & 3rd EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.000756902	0.000403113	0.000700643	0.00051614
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2 + (m_{\Delta j}^{k})^2}$ (m)	0.00149668	0.00150487	0.00142757	0.00138051
	DIFFERENCE (m)	0.000739778	0.001101757	0.000726927	0.00086437
B/W 1ST & 4th EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.000790569	0.0009005	0.00060208	0.000383275
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2 + (m_{\Delta j}^{k})^2}$ (m)	0.00152754	0.0015541	0.00146069	0.00152842
	DIFFERENCE (m)	0.000736971	0.0006536	0.00085861	0.001145145
B/W 1ST & 5th EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.000070711	0.000113137	0.000070711	0.000151327
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2 + (m_{\Delta j}^{k})^2}$ (m)	0.00149565	0.00150142	0.00142999	0.00149243
	DIFFERENCE (m)	0.001424939	0.001388283	0.001359279	0.001341103
B/W 1ST & 6th EPOCHS	**MAGNITUDE SQRT ((ΔN)²+(ΔE)²) (m)**	0.0007245	0.000471699	0.000750267	0.000509313
	$1.96\sqrt{(m_{\Delta j}^{k+1})^2 + (m_{\Delta j}^{k})^2}$ (m)	0.0014977	0.00154567	0.00171531	0.00140656
	DIFFERENCE (m)	0.0007732	0.001073971	0.000965043	0.000897247

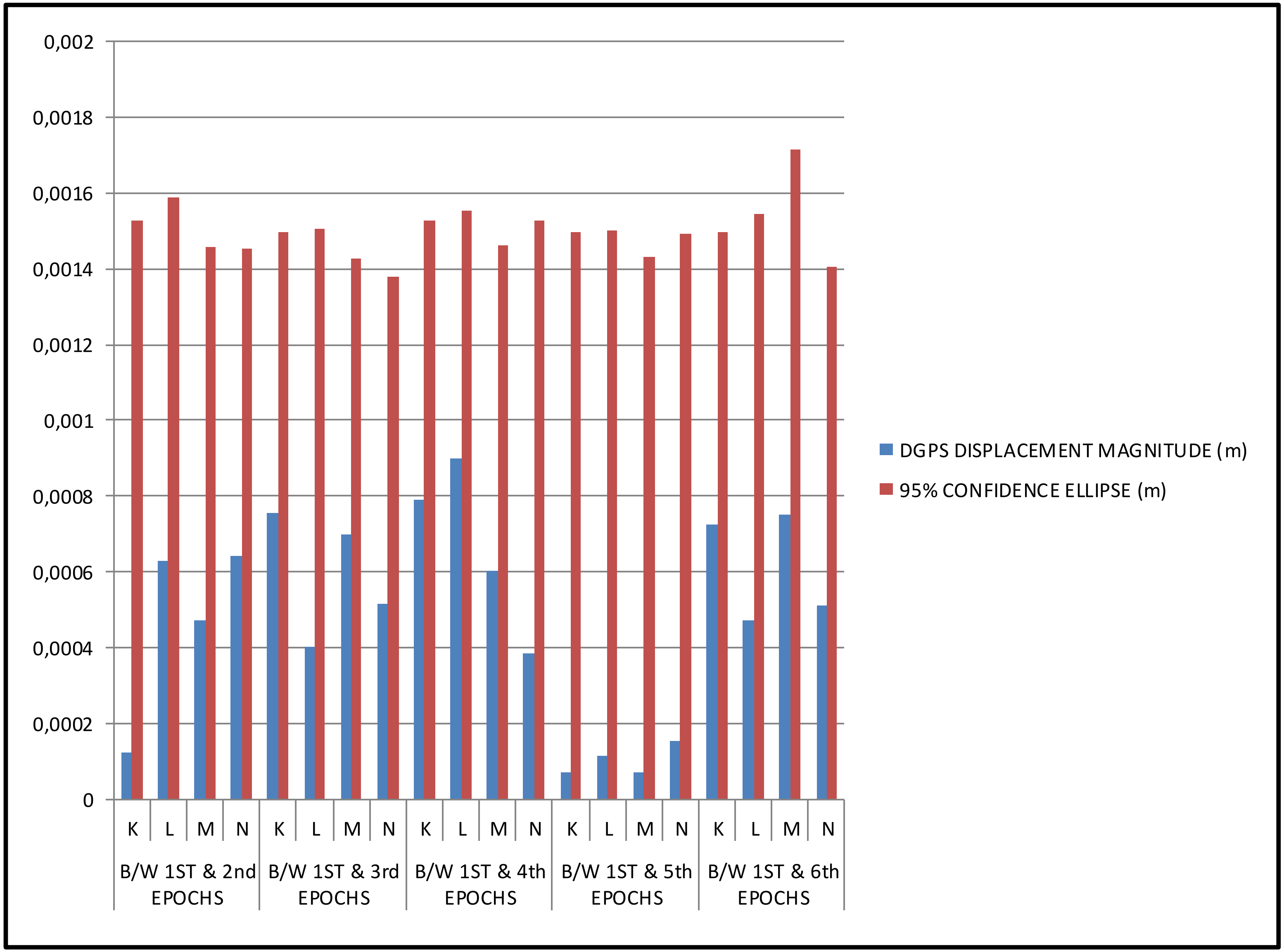


Fig 13: Plot of the Horizontal (DGPS Observations) Displacements Magnitudes and their Corresponding Confidence Ellipses

5.8 COMPARISON BETWEEN THE TENTH FLOOR AND THE ROOF MONITORING POINTS DISPLACEMENTS

The tenth floor and the roof monitoring points were compared to determine if movements have taken place at the tenth floor or not, that is to differentiate the movements of the tenth floor from those of the entire building.

5.10 COMPARISON OF THE TWO HORIZONTAL (ROOF MONITORING POINTS TOTAL STATION AND DGPS OBSERVATIONS) METHODS ACCURACY

Table 8: Comparison between the A Posteriori Standard Errors of the Adjusted Total Station and DGPS Epochs Observations of the Roof Monitoring Points

A POSTERIORI STANDARD ERROR (m) (ROOF MONITORING POINTS)		
	TOTAL STATION	**DGPS**
EPOCH 1	0.48126	0.002114344
EPOCH 2	0.37195	0.000559521
EPOCH 3	0.41917	0.000463080
EPOCH 4	0.32316	0.002458150
EPOCH 5	0.42506	0.002082528
EPOCH 6	0.42369	0.004780734

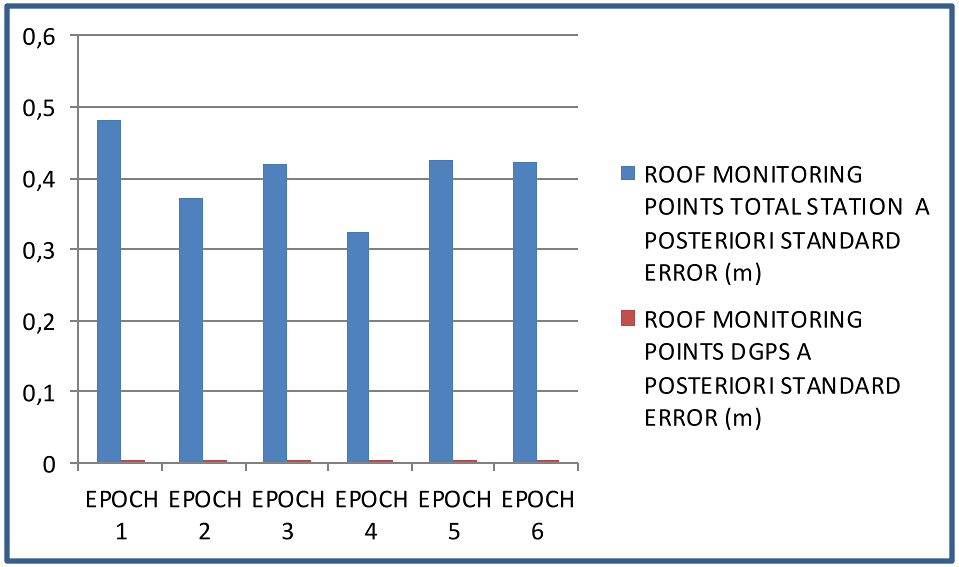


Fig 14: Plot of the A Posteriori Standard Errors of the Adjusted Total Station and DGPS Epochs Observations of the Roof Monitoring Points

Table 9: Comparison between the Variance Co-variance Matrices Traces of the Adjusted Total Station and DGPS Epochs Observations of the Roof Monitoring Points

VARIANCE CO-VARIANC MATRIX TRACE (m) (ROOF MONITORING POINTS)		
	TOTAL STATION	**DGPS**
EPOCH 1	0.000005577	0.000001979
EPOCH 2	0.000000755	0.000000392
EPOCH 3	0.000000958	0.000000223
EPOCH 4	0.000000569	0.000000425
EPOCH 5	0.000000985	0.000000308
EPOCH 6	0.000001027	0.000000510

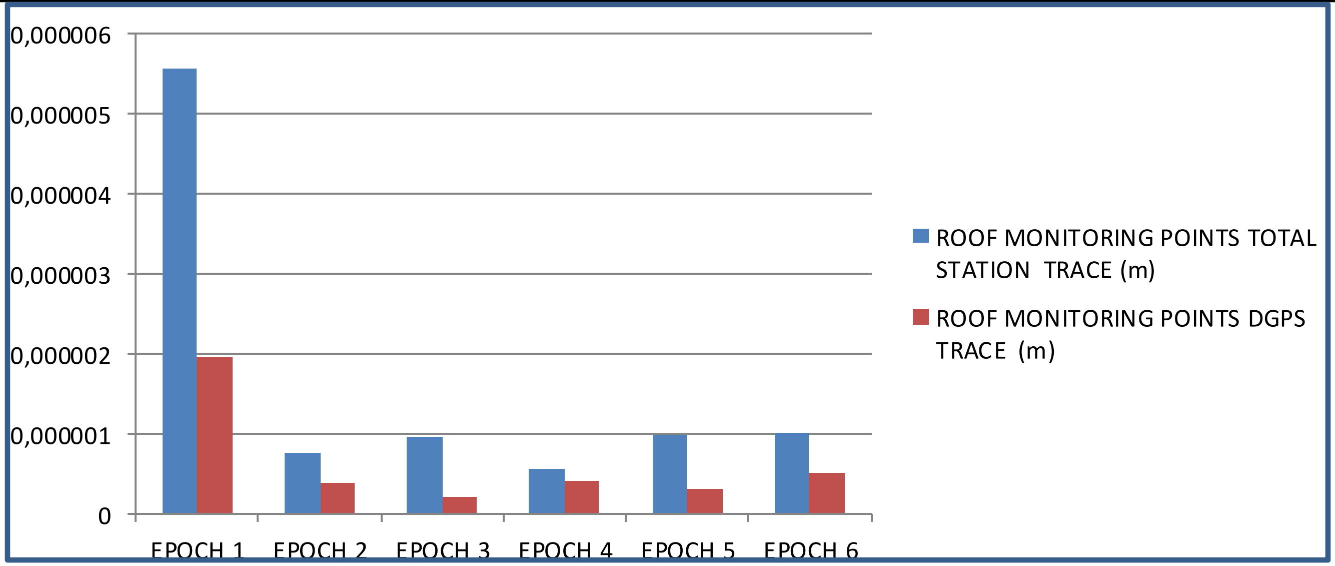


Fig 15: Plot of the Variance Co-variance Matrices Traces of the Adjusted Total Station and DGPS Epochs Observations of the Roof Monitoring Points

6.1 CONTRIBUTION TO KNOWLEDGE

- This study has monitored the vertical and horizontal deformation of Palm House, Benin City, compared the accuracy of the two employed horizontal methods and has made the following notable contributions to knowledge:
- The study has shown that the monitored structure, Palm House, Benin City was stable during the period of observation as there was no significant movement between epochs observations which in turn shows that the structure is still fit for usage.
- An approach for comparison of the two horizontal methods (DGPS and Total Station) using their standard error of unit weights and variance covariance matrices has been developed in this study.

7.1 CONCLUSION AND RECOMMENDATIONS

7.1.1 CONCLUSION

- The results of this study have shown that the building (Palm House) was stable during the period of observation.
- The study has also shown that the DGPS method is better than the total station method in terms of accuracy for deformation monitoring of engineering structures.
- This will assist users to decide on the method to apply as the selection of method depends upon the accuracy requirements for the survey.

7.1.2 RECOMMENDATIONS

The monitoring of engineering structures using more appropriate and accurate method for safety purpose cannot be undermined. Based on the result obtained from this study, the following recommendations were made:

- That whenever more suitable and accurate method of monitoring of engineering structures is to be employed between the DGPS and the total station methods, the DGPS method should be selected as this study has demonstrated and compared the accuracy of the two methods and shown that the DGPS method is better.

- That other geodetic methods of monitoring such as InSAR, etc should be compared with any of the two traditional (DGPS and Total Station) methods of monitoring of engineering structures to determine which is better in terms of accuracy.

- That the concrete strength of the monitored building (Palm House) should be investigated using non destructive measures such as Schmidt Hammer techniques as age and change in temperature affect the properties of the materials with which any engineering structure is being constructed and as there is a large crack on one of the walls of the 10th floor of the building.

7.3 SUGGESTIONS FOR FURTHER STUDIES

In the course of this study, it became understandable that other related researchable areas could not be covered in this work. Therefore, the topics below are posited for future study participation and contributions:

- Comparative analysis of DGPS and InSAR accuracy for horizontal deformation monitoring of engineering structures.
- Comparative analysis of Total Station and 3D laser scanning accuracy for horizontal deformation monitoring of engineering structures.
- Monitoring and modelling of the deformation of engineering structures using InSAR technology.

THANK YOU AND GOD BLESS